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(54) **Amplifier with configurable DC-coupled or AC-coupled output**

(57) A multi-mode amplifier with configurable DC-coupled or AC-coupled output is described. In one design, the multi-mode amplifier includes an amplifier and at least one DC level shifting circuit. The amplifier receives and amplifies an input signal and provides an output signal that is suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode. The at least one DC level shifting circuit

performs DC level shifting for at least one (e.g., input and/or output) common-mode voltage of the amplifier and is controlled based on whether the amplifier is operating in the DC-coupled or AC-coupled mode. The amplifier operates between VDD and VNEG supplies in the DC-coupled mode and between VDD and VSS supplies in the AC-coupled mode. The amplifier may include at least one gain stage, an internal DC level shifting circuit, and an output stage.

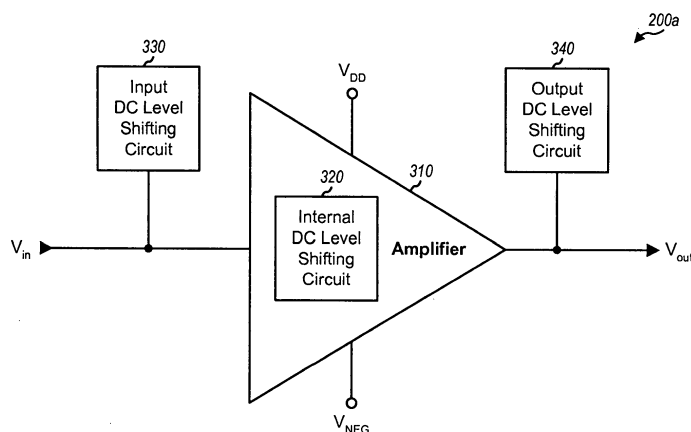


FIG. 3

Description**I. Claim of Priority under 35 U.S.C. §119**

5 [0001] The present Application for Patent claims priority to Provisional Application Serial No. 60/947,313, entitled "PROGRAMMABLE LEGACY AND GROUND-REFERENCED CAPLESS HEADPHONE POWER AMPLIFIER," filed June 29, 2007, assigned to the assignee hereof, and expressly incorporated herein by reference.

BACKGROUND**I. Field**

10 [0002] The present disclosure relates generally to electronics, and more specifically to an amplifier.

II. Background

15 [0003] Amplifiers are commonly used to amplify and/or buffer signals to obtain the desired signal level and/or signal drive. Amplifiers are widely used for various applications such as communication, computing, networking, consumer electronics, etc. For example, in a wireless communication device such as a cellular phone, amplifiers may be used to drive headphones, earpieces, etc. It may be desirable for these amplifiers to provide the desired signal drive and/or have low power consumption.

SUMMARY

25 [0004] A multi-mode amplifier with configurable DC-coupled or AC-coupled output is described herein. DC stands for direct current, and AC stands for alternating current. DC coupling refers to coupling of an output signal directly to a load. AC coupling refers to coupling of an output signal to a load via a capacitor, which acts as a DC block. The multi-mode amplifier may be used as a headphone amplifier and/or for other output amplifiers.

30 [0005] In one design, the multi-mode amplifier includes an amplifier and at least one DC level shifting circuit. The amplifier receives and amplifies an input signal and provides an output signal that is suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode. The at least one DC level shifting circuit performs DC level shifting as needed for at least one (e.g., input and/or output) common-mode voltage of the amplifier. The at least one DC level shifting circuit is controlled based on whether the amplifier is operating in the DC-coupled mode or the AC-coupled mode.

35 [0006] The amplifier may operate between an upper power supply V_{DD} and a first lower power supply V_{NEG} in the DC-coupled mode and between the upper power supply and a second lower power supply V_{SS} in the AC-coupled mode. The amplifier may include at least one gain stage to provide amplification, an internal DC level shifting circuit, and an output stage. The internal DC level shifting circuit may provide a first internal common-mode voltage in the DC-coupled mode and a second internal common-mode voltage in the AC-coupled mode. The output stage may include (i) a first output drive section to provide signal drive in both the DC-coupled and AC-coupled modes and (ii) a second output drive section to provide additional signal drive in the AC-coupled mode.

40 [0007] Various aspects and features of the disclosure are described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS**[0008]**

45 FIG. 1 shows a block diagram of an audio circuit.

FIG. 2A shows operation of a multi-mode amplifier in the DC-coupled mode.

50 FIG. 2B shows operation of the multi-mode amplifier in the AC-coupled mode.

FIG. 3 shows a design of the multi-mode amplifier.

FIG. 4 shows another design of the multi-mode amplifier.

FIGS. 5A and 5B show two additional designs of the multi-mode amplifier.

FIGS. 6 and 7 show two designs of an amplifier within the multi-mode amplifier.

55 FIG. 8 shows a process for configuring the multi-mode amplifier.

FIG. 9 shows a process for operating the multi-mode amplifier.

FIG. 10 shows a block diagram of a wireless communication device.

DETAILED DESCRIPTION

[0009] The multi-mode amplifier with configurable DC-coupled or AC-coupled output described herein may be used for various applications such as audio, video, input/output (I/O) interface, etc. For clarity, the use of the multi-mode amplifier for audio is described below.

[0010] FIG. 1 shows a block diagram of an audio circuit 100, which may be used for a cellular phone and other electronics devices. Within audio circuit 100, a stereo digital-to-analog converter (DAC) 110 may receive audio data, convert the data from digital to analog, and provide analog signals for left, right, and mono. A mixer/router 120 may receive the analog signals from DAC 110 and a line in signal, combine and/or route the signals as appropriate, and provide input signals to a headphone amplifier 130, an earpiece amplifier 132, and a line out amplifier 134. Each output amplifier 130 to 134 may amplify and/or buffer its input signal and provide a corresponding output signal. In general, any number of output amplifiers may be used to provide any number of output signals for any type of output devices.

[0011] The multi-mode amplifier with configurable DC-coupled or AC-coupled output may be used for headphone amplifier 130 and/or other output amplifiers. Either DC-coupled output or AC-coupled output may be selected by controlling support circuitry for the multi-mode amplifier, as described below.

[0012] FIG. 2A shows operation of a multi-mode amplifier 200 in a DC-coupled mode, which may also be referred to as a capless mode, a ground-reference mode, a ground-reference capless mode, etc. In the DC-coupled mode, multi-mode amplifier 200 may operate between an upper power supply V_{DD} and a lower power supply V_{NEG} and may directly drive an output load 150. The DC-coupled mode may be used to eliminate an AC coupling capacitor at the amplifier output and to reduce component count and bill of material (BOM).

[0013] FIG. 2B shows operation of multi-mode amplifier 200 in an AC-coupled mode, which may also be referred to as a capacitor-coupled mode, a legacy mode, a legacy capacitor-coupled mode, etc. In the AC-coupled mode, multi-mode amplifier 200 may operate between the upper power supply V_{DD} and a circuit ground V_{SS} and may drive output load 150 via an AC-coupling capacitor 140. The AC-coupled mode may be used to reduce power consumption.

[0014] The ability of multi-mode amplifier 200 to support both the DC-coupled and AC-coupled modes for headphone amplifier 130 and/or other output amplifiers may be desirable for several reasons. First, multi-mode amplifier 200 may be used by a wider customer base. Each customer can operate the multi-mode amplifier in either the DC-coupled mode or the AC-coupled mode based on that customer's preference for lower power consumption or reduced component count and cost. Second, multi-mode amplifier 200 can avoid the need to have two separate output amplifiers - one output amplifier with DC-coupled output and another output amplifier with AC-coupled output.

[0015] Multi-mode amplifier 200 may have a particular input common-mode voltage V_{CM-IN} , a particular internal common-mode voltage V_{CM-INT} , and a particular output common-mode voltage V_{CM-OUT} . A common-mode voltage is an average or DC voltage for a single-ended signal or a differential signal. Different power supply voltages and different common-mode voltages may be used for the DC-coupled and AC-coupled modes in order to achieve the desired signal swing.

[0016] FIG. 3 shows a block diagram of a multi-mode amplifier 200a that supports the DC-coupled and AC-coupled modes. Multi-mode amplifier 200a is one design of multi-mode amplifier 200 in FIGS. 2A and 2B and may be used for headphone amplifier 130 in FIG. 1. In this design, multi-mode amplifier 200a includes an amplifier 310, an input DC level shifting circuit 330, and an output DC level shifting circuit 340. Amplifier 310 operates between V_{DD} and a lower power supply V_{EE} , where $V_{EE} = V_{NEG}$ for the DC-coupled mode and $V_{EE} = V_{SS}$ for the AC-coupled mode. Circuit 330 may perform DC level shifting, as needed, such that a desired input common-mode voltage can be obtained for each of the DC-coupled and AC-coupled modes. Similarly, circuit 340 may perform DC level shifting, as needed, such that a desired output common-mode voltage can be obtained for each mode. Amplifier 310 includes an internal DC level shifting circuit 320 that may perform DC level shifting, as needed, such that a desired internal common-mode voltage can be obtained for each mode.

[0017] In general, input DC level shifting circuit 330 may be used to obtain different input common-mode voltages for the two modes or may be omitted if the same input common-mode voltage is used for the two modes. Output DC level shifting circuit 340 may be used to obtain different output common-mode voltages for the two modes or may be omitted if the same output common-mode voltage is used for the two modes. Internal DC level shifting circuit 320 may be used to obtain different internal common-mode voltages for the two modes or may be omitted if the same internal common-mode voltage is used for the two modes.

[0018] Table 1 gives the power supplies and the common-mode voltages for multi-mode amplifier 200a for the DC-coupled and AC-coupled modes in accordance with one design.

Table 1

Parameter	Symbol	DC-coupled Mode	AC-coupled Mode
Upper power supply	V_{DD}	V_{DD}	V_{DD}
Lower power supply	V_{EE}	V_{NEG}	V_{SS}
Input common-mode voltage	V_{CM-IN}	V_{CM}	V_{CM}
Internal common-mode voltage	V_{CM-INT}	V_{SS}	V_{CM}
Output common-mode voltage	V_{CM-OUT}	V_{SS}	V_{CM}

[0019] In the design shown in Table 1, the same input common-mode voltage is used for both modes, and different internal and output common-mode voltages are used for the two modes. In this design, DC level shifting circuits 320 and 340 may be used to obtain different internal and output common-mode voltages for the two modes. DC level shifting circuit 330 may be omitted since the same input common-mode voltage is used for the two modes.

[0020] In general, V_{DD} , V_{EE} , V_{CM-IN} , V_{CM-INT} and V_{CM-OUT} may each be the same value or different values for the two modes. Furthermore, any suitable voltages may be used for V_{DD} , V_{EE} , V_{CM-IN} , V_{CM-INT} and V_{CM-OUT} for each mode. The voltages may be selected based on various factors such as the available power supply voltages, the desired output signal swing, the desired power consumption, the integrated circuit (IC) process used to fabricate the multi-mode amplifier, etc. In one specific design, $V_{DD} = 2.1$ volts (V), $V_{NEG} = -1.8$ V, $V_{SS} = 0$ V, and $V_{CM} = 1.0$ V. Other voltages may also be used for V_{DD} , V_{NEG} , V_{SS} and V_{CM} .

[0021] In one design, a decision to operate multi-mode amplifier 200 in the DC-coupled mode or the AC-coupled mode may be made during the design phase of an electronics device (e.g., a cellular phone) in which the multi-mode amplifier is used. The lower power supply V_{EE} for amplifier 310 may then be coupled directly to either a power bus for V_{NEG} or circuit ground V_{SS} depending on the selected mode. This direct connection of V_{EE} may reduce voltage drop across the connection and may improve the performance of amplifier 310. In another design, V_{EE} for amplifier 310 may be coupled to either V_{NEG} or V_{SS} via a power switch, which may be controlled based on the selected mode. This design may allow for dynamic switching between the DC-coupled and AC-coupled modes.

[0022] FIG. 4 shows a schematic diagram of a multi-mode amplifier 200b that supports the DC-coupled and AC-coupled modes. Multi-mode amplifier 200b is another design of multi-mode amplifier 200 in FIGS. 2A and 2B and may also be used for headphone amplifier 130 in FIG. 1. In this design, multi-mode amplifier 200b includes an amplifier section 402 and an output DC level shifting circuit 440. Within amplifier section 402, an amplifier 410 operates between V_{DD} and V_{EE} , where V_{EE} is dependent on whether the DC-coupled or AC-coupled mode is selected. A resistor 412 has one end receiving a V_{inn} input signal and the other end coupled to an inverting input of amplifier 410. A resistor 414 has one end receiving a V_{inp} input signal and the other end coupled to a non-inverting input of amplifier 410. A feedback resistor 416 is coupled between the inverting input and the output of amplifier 410. An operational amplifier (op-amp) 422 is coupled as a unity gain buffer and receives and buffers the common-mode voltage V_{CM} . A resistor 424 is coupled between the output of op-amp 422 and the non-inverting input of amplifier 410.

[0023] Within output DC level shifting circuit 440, a current source 450 is coupled in series with a switch 448, and the combination is coupled between V_{DD} and the inverting input of amplifier 410. A switch 458 is coupled in series with a current source 460, and the combination is coupled between the output of amplifier 410 and V_{NEG} .

[0024] Multi-mode amplifier 200b operates as follows. Op-amp 422 sets the input common-mode voltage of amplifier 410 to V_{CM} . Amplifier 410 receives a differential input signal composed of the V_{inp} and V_{inn} signals and provides a single-ended output signal V_{out} . DC level shifting circuit 440 sets the output common-mode voltage of amplifier 410 to 0V in the DC-coupled mode and to V_{CM} in the AC-coupled mode. In the DC-coupled mode, switches 448 and 458 are closed, and an offset current of $I_{OS} = V_{CM} / R$ from current source 450 flows through feedback resistor 416 and causes a voltage drop of V_{CM} across resistor 416, which then results in the output of amplifier 410 being at 0V. Current source 460 draws the I_{OS} current from the output of amplifier 410 to V_{NEG} so that this I_{OS} current is not provided to the output signal V_{out} . In the AC-coupled mode, switches 448 and 458 are opened, and the output common-mode voltage is equal to the input common-mode voltage due to feedback resistor 416.

[0025] FIG. 5A shows a schematic diagram of a multi-mode amplifier 200c, which is one design of multi-mode amplifier 200b in FIG. 4. In this design, multi-mode amplifier 200c includes amplifier section 402 and an output DC level shifting circuit 540a. Amplifier section 402 is described above for FIG. 4.

[0026] Within output DC level shifting circuit 540a, an op-amp 542 receives the V_{CM} voltage at a non-inverting input. An N-channel field effect transistor (N-FET) 544 has its gate coupled to the output of op-amp 542 and its source coupled to an inverting input of op-amp 542. A resistor 546 is coupled between the source of N-FET 544 and circuit ground. P-channel FETs (P-FETs) 550a, 550b and 550c are coupled as a PMOS current mirror and have their sources coupled

to V_{DD} and their gates coupled together and to the drain of P-FET 550a. A switch 548a is coupled between the drain of P-FET 550a and the drain of N-FET 544. A switch 548b is coupled between the drain of P-FET 550b and the inverting input of op-amp 410. N-FETs 560a and 560b are coupled as an NMOS current mirror and have their sources coupled to V_{NEG} and their gates coupled together and to the drain of N-FET 560b. A switch 548c is coupled between the drain of P-FET 550c and the drain of N-FET 560b. The drain of N-FET 560a is coupled to the output of amplifier 410.

[0027] DC level shifting circuit 540a sets the output common-mode voltage of amplifier 410 to 0V in the DC-coupled mode and to V_{CM} in the AC-coupled mode. In the DC-coupled mode, switches 548a, 548b and 548c are closed, a current of $I_{OS} = V_{CM} / R$ is generated through resistor 546, and this I_{OS} current flows through each of P-FETs 550a, 550b and 550c due to the PMOS current mirror configuration. The I_{OS} current from P-FET 550b flows through feedback resistor 416 and causes a voltage drop of V_{CM} across resistor 416, which then results in the output of amplifier 410 being at 0V. The I_{OS} current from P-FET 550c flows through N-FET 560b, and a current of I_{OS} also flows through N-FET 560a due to the NMOS current mirror configuration. N-FET 560a thus draws the I_{OS} current from P-FET 550b to V_{NEG} so that this I_{OS} current is not provided to the output signal V_{out} . In the AC-coupled mode, switches 548a, 548b and 548c are opened, and the output common-mode voltage is equal to the input common-mode voltage due to feedback resistor 416.

[0028] FIG. 5B shows a schematic diagram of a multi-mode amplifier 200d, which is another design of multi-mode amplifier 200b in FIG. 4. In this design, multi-mode amplifier 200d includes amplifier section 402 and an output DC level shifting circuit 540b. Amplifier section 402 is described above for FIG. 4. DC level shifting circuit 540b includes all of the circuit components in DC level shifting circuit 540a in FIG. 5A as well as some additional circuit components.

[0029] Within DC level shifting circuit 540b, the PMOS current mirror further includes a P-FET 550d coupled in parallel with P-FET 550c. Resistors 552a, 552b, 552c and 552d are coupled between V_{DD} and the sources of P-FETs 550a, 550b, 550c and 550d, respectively. P-FETs 554c and 554d have their sources coupled to the drains of P-FETs 550c and 550d, respectively, and their gates coupled together and to the drain of P-FET 554c. The NMOS current mirror further includes N-FETs 562a, 562b and 562c having their gates coupled together. N-FET 562a has its source coupled to the drain of N-FET 560a and its drain coupled to the output of amplifier 410. N-FET 562b has its source coupled to the drain of N-FET 560b and its drain coupled to the gates of N-FETs 560a and 560b. N-FET 562c has its source coupled to V_{NEG} and its gate coupled to its drain. Switches 548c and 548d are coupled between the drains of P-FETs 554c and 554d and the drains of N-FETs 562b and 562c, respectively.

[0030] Resistors 552a through 552d provide source degeneration, which may reduce noise. P-FETs 554c and 554d are cascode transistors used to reduce the drain-to-source voltage V_{ds} across P-FETs 550c, 550d, 554c and 554d. N-FETs 562a, 562b and 562c are thick-oxide transistors that are able to handle a larger V_{ds} . For example, the V_{out} signal may swing from +1.414V to -1.414V, the V_{ds} of N-FET 562a may be greater than 2.2V, and the use of thick-oxide may allow N-FET 562a to handle this larger V_{ds} . In one design, $V_{DD} - V_{NEG} = 3.9V$, and the break down voltage of the thick-oxide transistors is greater than 6V in order to provide some margins. In the figures, the thick-oxide transistors are indicated by darker vertical bars at their gates. The additional P-FETs and N-FETs in DC level shifting circuit 540b may improve reliability.

[0031] In one design, switches 548c and 548d are implemented with FETs of sufficient length (e.g., greater than 0.5 μm) in order to keep the shift in threshold voltage V_t below a desired percentage (e.g., 20%) over the expected lifetime (e.g., 5 years) of the multi-mode amplifier. Switches 548c and 548d may also be designed to handle gate-to-source voltage V_{gs} and V_{ds} greater than $V_{DD} - V_{NEG}$ (e.g., 4.1V).

[0032] FIGS. 4, 5A and 5B show example designs in which a desired output common-mode voltage is obtained by controlling the amount of DC current flowing through feedback resistor 416. The desired output common-mode voltage may also be obtained with other DC level shifting circuit designs.

[0033] FIG. 6 shows a schematic diagram of an amplifier 410a, which is one design of amplifier 410 in FIGS. 4, 5A and 5B. In this design, amplifier 410a includes a first gain stage 610, an internal DC level shifting circuit 620, a second gain stage 630, and an output stage 640. First gain stage 610 receives a differential input signal composed of V_{ip} and V_{in} input signals and provides a V_1 output signal. First gain stage 610 operates between V_{DD} and V_{SS} and has an input common-mode voltage of V_{CM} for both the DC-coupled and AC-coupled modes. The input common-mode voltage V_{CM} is set by op-amp 422 in FIG. 4.

[0034] Within DC level shifting circuit 620, an N-FET 622 has its gate receiving the V_1 signal from first gain stage 610, its drain coupled to V_{DD} , and its source providing a V_2 output signal. A switch 624 and a current source 626 are coupled in series, and the combination is coupled between the source of N-FET 622 and V_{NEG} . A switch 628 is coupled between the gate and source of N-FET 622. In the DC-coupled mode, switch 624 is closed, switch 628 is opened, and DC level shifting circuit 620 shifts the DC level of the V_1 signal down to V_{SS} via N-FET 622 and provides the DC-shifted V_1 signal as the V_2 signal. The amount of DC shift may be determined based on the size of N-FET 622 and the amount of bias current from current source 626. In the AC-coupled mode, switch 624 is opened, switch 628 is closed, and DC level shifting circuit 620 passes the V_1 signal via switch 628 as the V_2 signal.

[0035] Second gain stage 630 receives the V_2 signal from DC level shifting circuit 620 and an internal common-mode voltage V_{CM-INT} from a switch 632 and provides a V_3 output signal. Switch 632 provides V_{SS} in the DC-coupled mode

and provides V_{CM} in the AC-coupled mode. In the DC-coupled mode, second gain stage 630 operates between V_{DD} and V_{NEG} , and the common-mode voltage at the input of second gain stage 630 is equal to V_{SS} from switch 632. In the AC-coupled mode, second gain stage 630 operates between V_{DD} and V_{SS} , and the common-mode voltage at the input of second gain stage 630 is equal to V_{CM} from switch 632. Output stage 640 receives the V_3 signal from second gain stage 630 and provides the output signal V_{out} for amplifier 410. Output stage 640 operates between V_{DD} and V_{EE} , with V_{EE} being dependent on the selected mode.

[0036] In the design shown in FIG. 6, first gain stage 610 operates between the same supplies of V_{DD} and V_{SS} for both the DC-coupled and AC-coupled modes whereas second gain stage 630 and output stage 640 operate between supplies of V_{DD} and V_{NEG} in the DC-coupled mode and between supplies of V_{DD} and V_{SS} in the AC-coupled mode. DC level shifting circuit 620 is used to vary the common-mode voltage at the input of second gain stage 630 to match the change in the supplies for the second gain stage.

[0037] FIG. 7 shows a schematic diagram of an amplifier 410b, which is another design of amplifier 410 in FIGS. 4, 5A and 5B. In this design, amplifier 410b includes a first gain stage 710, an internal DC level shifting circuit 730, a second gain stage 740, a third gain stage 750, a biasing output stage 770, and a class AB output stage 790.

[0038] First gain stage 710 implements an operational transconductance amplifier (OTA) and includes a differential pair 712 and a cascode buffer 720. Within differential pair 712, P-FETs 714a and 714b have their gates receiving the V_{in} and V_{ip} input signals, respectively, and their sources coupled together. N-FETs 716a and 716b have their sources coupled to V_{SS} , their gates receiving a V_{bn1} bias voltage, and their drains coupled to the drains of P-FETs 714a and 714b, respectively. A P-FET 718 has its source coupled to V_{DD} , its gate receiving a V_{bp1} bias voltage, and its drain coupled to the sources of P-FETs 714a and 714b. P-FET 718 functions as a current source. P-FETs 714a and 714b operate as a differential pair. N-FETs 716a and 716b provide an active load for the differential pair.

[0039] Within cascode buffer 720, N-FETs 722a and 722b have their sources coupled to the drains of N-FETs 716a and 716b, respectively, and their gates receiving a V_{bn2} bias voltage. P-FETs 724a and 724b have their drains coupled to the drains of N-FETs 722a and 722b, respectively, and their gates receiving a V_{bp2} bias voltage. P-FETs 726a and 726b have their sources coupled to V_{DD} , their gates coupled together and to the drain of P-FET 724a, and their drains coupled to the sources of P-FETs 724a and 724b, respectively. The drains of FETs 722b and 724b provide a V_1 output signal for first gain stage 710.

[0040] Within DC level shifting circuit 730, N-FETs 732, 734 and 736 are stacked and coupled between V_{DD} and V_{NEG} . N-FET 732 has its drain coupled to V_{DD} , its gate receiving the V_1 signal from first gain stage 710, and its source coupled to the drain of N-FET 734. N-FET 734 has its gate receiving a DC Mode signal, and its source coupled to the drain of N-FET 736. N-FET 736 has its gate receiving a V_{bn3} bias voltage and its source coupled to V_{EE} . An N-FET 738 has its source coupled to the gate of N-FET 732, its gate receiving an AC Mode signal, and its drain coupled to the source of N-FET 732. N-FET 732 performs DC level shifting of the V_1 signal. N-FETs 734 and 738 correspond to switches 624 and 628, respectively, in FIG. 6. N-FET 736 corresponds to current source 626 in FIG. 6. The source of N-FET 732 provides a V_2 output signal for DC level shifting circuit 730. The DC Mode and AC Mode signals may be designed for operation between V_{DD} and V_{EE} and may be obtained by level shifting digital control signals.

[0041] Second gain stage 740 includes P-FETs 744a, 744b and 748 and N-FETs 746a and 746b that are coupled in similar manner as P-FETs 714a, 714b and 718 and N-FETs 716a and 716b in first gain stage 710. P-FET 744a receives the V_2 signal at its gate, P-FET 744b receives the V_{CM-INT} voltage at its gate, and P-FET 748 receives a V_{bp3} bias voltage at its gate. The drains of FETs 744b and 746b provide a V_3 output signal for second gain stage 740.

[0042] Within third gain stage 750, an N-FET 752 has its source coupled to V_{EE} and its gate receiving the V_3 signal. An N-FET 754 has its source coupled to the drain of N-FET 752, its gate receiving a V_{bn4} bias voltage, and its drain coupled to the drain of a P-FET 756a. P-FETs 756a and 756b have their sources coupled to V_{DD} and their gates coupled together and to the drain of P-FET 756a. The drain of P-FET 756b provides a V_4 signal. An N-FET 758 has its source coupled to V_{EE} , its gate receiving the V_{bn3} bias voltage, and its drain providing a V_5 signal. An N-FET 760 has its source coupled to the drain of N-FET 758, its gate receiving the V_{bn4} bias voltage, and its drain coupled to the drain of P-FET 756b. A P-FET 762 has its source coupled to the drain of P-FET 756b, its gate receiving a V_{bp4} bias voltage, and its drain coupled to the drain of N-FET 758. N-FET 752 operates as a common source amplifier. N-FET 754 functions as a cascode buffer. P-FETs 756a and 756b operate as a PMOS current mirror load. N-FET 760 and P-FET 762 are floating voltage sources that provide the V_4 and V_5 signals to drive output stage 790.

[0043] Within biasing output stage 770, FETs 772, 774 and 776 are stacked and coupled between V_{DD} and V_{EE} . N-FET 772 has its source coupled to V_{EE} and its gate coupled to its drain. N-FET 774 has its source coupled to the drain of N-FET 772 and its gate coupled to its drain, which provides the V_{bn4} bias voltage. P-FET 776 has its source coupled to V_{DD} , its gate receiving the V_{bp3} bias voltage, and its drain coupled to the drain of N-FET 774. N-FET 782 has its source coupled to V_{EE} and its gate receiving the V_{bn3} bias voltage. P-FET 784 has its gate and drain coupled to the drain of N-FET 782 and its drain providing the V_{bp4} bias voltage. P-FET 786 has its source coupled to V_{DD} , its gate coupled to its drain, and its drain coupled to the source of P-FET 784. The FETs within biasing output stage 770 provide the V_{bn4} and V_{bp4} bias voltages for third gain stage 750.

[0044] Within class AB output stage 790, N-FETs 792a and 792b have their sources coupled to V_{EE} and their drains coupled to an output node that provides the output signal V_{out} . The gate of N-FET 792a receives the V_5 signal directly whereas the gate of N-FET 792b receives the V_5 signal via a switch 796a. A switch 798a is coupled between the gate of N-FET 792b and V_{EE} . P-FETs 794a and 794b have their sources coupled to V_{DD} and their drains coupled to the output node. The gate of P-FET 794a receives the V_4 signal directly whereas the gate of P-FET 794b receives the V_4 signal via a switch 796b. A switch 798b is coupled between the gate of P-FET 794b and V_{DD} . Each pair of FETs 792 and 794 form an output drive section that provides signal drive for the V_{out} signal.

[0045] In the design shown in FIG. 7, different numbers of output drive sections are used for the DC-coupled and AC-coupled modes. In the DC-coupled mode, output stage 790 operates with a larger supply between V_{DD} and V_{EE} , the transconductances g_m of FETs 792a and 794a are higher, and FETs 792a and 794a can provide the desired output drive. FETs 792b and 794b may be disabled by opening switches 796a and 796b and closing switches 798a and 798b. In the AC-coupled mode, output stage 790 operates with a smaller supply between V_{DD} and V_{SS} , the transconductances of FETs 792a and 794a are smaller, and FETs 792a and 794a as well as FETs 792b and 794b are used to provide the desired output drive. FETs 792b and 794b may be enabled by closing switches 796a and 796b and opening switches 798a and 798b. In general, any number of FET pairs for any number of output drive sections may be used to provide the desired signal drive for each of the DC-coupled and AC-coupled modes.

[0046] Capacitors 702, 704, 706 and 708 are compensation capacitors used to ensure stability of amplifier 410b. Capacitor 702 is coupled between the gate and drain of N-FET 792a. Capacitor 704 is coupled between the gate and drain of P-FET 794a. Capacitor 706 is coupled between the output node and the gate of N-FET 732. Capacitor 708 is coupled between the output node and the gate of N-FET 752. The compensation may attempt to separate the poles from each of the gain stages sufficiently far apart in order to obtain the desired gain and phase margin in both of the DC-coupled and AC-coupled modes. In addition, the compensation capacitor for a given stage (e.g., capacitor 708 for third gain stage 750) may be switched between the two modes.

[0047] In one design, first gain stage 710 operates between $V_{DD} = 2.1V$ and $V_{SS} = 0V$ and is implemented with thin-oxide FETs. The subsequent stages operate between $V_{DD} = 2.1V$ and $V_{NEG} = -1.8V$ and are implemented with thick-oxide FETs having a higher operating voltage than the thin-oxide FETs. The thick-oxide FETs are shown with darker vertical bars at their gates. The N-FETs coupled to V_{NEG} may be isolated from the substrate using a deep N-well. Some of the thick-oxide FETs (e.g., N-FET 760 and P-FET 762) may have their bulk tied to their sources in order to combat bulk effect in the AC-coupled mode.

[0048] In one design, amplifiers 410a and 410b operate between $V_{DD} = 2.1V$ and $V_{NEG} = -1.8V$ in the DC-coupled mode and can provide a maximum output signal swing of 1 Vrms with an output common-mode voltage of $V_{CM} = 0V$ into a load of 16 ohms (Ω). In one design, amplifiers 410a and 410b operate between $V_{DD} = 2.1V$ and $V_{SS} = 0V$ in the AC-coupled mode and can provide a maximum output signal swing of 0.58 Vrms with an output common-mode voltage of $V_{CM} = 1V$ into the 16 Ω load. Amplifiers 410a and 410b may also be operated with other V_{DD} and V_{EE} voltages and may be able to provide other output signal levels for the DC-coupled and AC-coupled modes.

[0049] FIGS. 6 and 7 show example designs of two amplifiers 410a and 410b that can support the DC-coupled and AC-coupled modes. An amplifier supporting these two modes may also be implemented with other designs. In general, an amplifier may have any number of gain stages. A given stage may operate with the same supplies (e.g., V_{DD} and V_{SS}) for both the DC-coupled and AC-coupled modes or with different supplies for the two modes (e.g., V_{DD} and V_{NEG} for the DC-coupled mode and V_{DD} and V_{SS} for the AC-coupled mode). The amplifier may or may not employ an internal DC level shifting circuit. If employed, the internal DC level shifting circuit may be used to center the common-mode voltage when different supplies are used for the two modes.

[0050] FIG. 8 shows a design of a process 800 for configuring a multi-mode amplifier, e.g., multi-mode amplifier 200a, 200b, 200c or 200d in FIG. 3, 4, 5A or 5B, respectively. A determination is made whether the amplifier is operated in the DC-coupled or AC-coupled mode (block 810). If the amplifier is operated in the DC-coupled mode, then the power supplies for the amplifier may be set to V_{DD} and V_{NEG} (block 812). An output DC level shifting circuit may be enabled to obtain an output common-mode voltage of V_{SS} (block 814). An internal DC level shifting circuit may also be enabled to obtain an internal common-mode voltage of V_{SS} (block 816). A sufficient number of output drive sections (N1) may be enabled to obtain the desired signal drive in the DC-coupled mode (block 818).

[0051] If the amplifier is operated in the AC-coupled mode, then the power supplies for the amplifier may be set to V_{DD} and V_{SS} (block 822). The output DC level shifting circuit may be disabled to obtain an output common-mode voltage of V_{CM} (block 824). The internal DC level shifting circuit may also be disabled to obtain an internal common-mode voltage of V_{CM} (block 826). A sufficient number of output drive sections (N2) may be enabled to obtain the desired signal drive in the AC-coupled mode, where N2 may be greater than N1 for the DC-coupled mode (block 828).

[0052] FIG. 8 shows a specific design of configuring a multi-mode amplifier in either the DC-coupled or AC-coupled mode. The internal DC level shifting circuit may be omitted if the same internal common-mode voltage is used for both modes. Different and/or additional circuits may also be configured for the two modes. For example, an input DC level shifting circuit may be used to obtain different input common-mode voltages for the two modes, compensation capacitors

may be switched between the two modes, etc.

[0053] FIG. 9 shows a design of a process 900 for operating a multi-mode amplifier, e.g., multi-mode amplifier 200a, 200b, 200c or 200d in FIG. 3, 4, 5A or 5B, respectively. An input signal may be amplified to obtain an output signal that is suitable for DC coupling to a load in the DC-coupled mode and for AC coupling to the load in the AC-coupled mode (block 912). For block 912, the input signal may be amplified using (i) an upper power supply V_{DD} and a first lower power supply V_{NEG} in the DC-coupled mode and (ii) the upper power supply and a second lower power supply V_{SS} in the AC-coupled mode. The output signal may be driven (i) with a first output drive section in both the DC-coupled and AC-coupled modes and (ii) further with a second output drive section in the AC-coupled mode.

[0054] DC level shifting may be performed as needed to obtain a first output common-mode voltage (e.g., V_{SS}) for the output signal in the DC-coupled mode and to obtain a second output common-mode voltage (e.g., V_{CM}) for the output signal in the AC-coupled mode (block 914). For block 914, an offset current may be generated to obtain a DC voltage difference between the input signal and the output signal. The offset current may be drawn to a lower power supply to prevent the offset current from passing to the output signal. DC level shifting may also be performed as needed to obtain a first internal common-mode voltage (e.g., V_{SS}) in the DC-coupled mode and to obtain a second internal common-mode voltage (e.g., V_{CM}) in the AC-coupled mode (block 916).

[0055] The multi-mode amplifier described herein may be used for various applications such as communication, computing, networking, personal electronics, etc. For example, the multi-mode amplifier may be used for wireless communication devices, cellular phones, personal digital assistants (PDAs), handheld devices, gaming devices, computing devices, laptop computers, consumer electronics devices, personal computers, cordless phones, etc. An example use of the multi-mode amplifier in a wireless communication device is described below.

[0056] FIG. 10 shows a block diagram of a design of a wireless communication device 1000 for a wireless communication system. Wireless device 1000 may be a cellular phone, a terminal, a handset, a wireless modem, etc. The wireless communication system may be a Code Division Multiple Access (CDMA) system, a Global System for Mobile Communications (GSM) system, etc.

[0057] Wireless device 1000 is capable of providing bi-directional communication via a receive path and a transmit path. On the receive path, signals transmitted by base stations may be received by an antenna 1012 and provided to a receiver (RCVR) 1014. Receiver 1014 may condition and digitize the received signal and provide samples to a section 1020 for further processing. On the transmit path, a transmitter (TMTR) 1016 may receive data to be transmitted from section 1020, process and conditions the data, and generate a modulated signal, which may be transmitted via antenna 1012 to the base stations. Receiver 1014 and transmitter 1016 may support CDMA, GSM, etc.

[0058] Section 1020 includes various processing, interface, and memory units such as, for example, a modem processor 1022, a reduced instruction set computer/digital signal processor (RISC/DSP) 1024, a controller/processor 1026, a memory 1028, an audio processor 1030, audio drivers 1032, an external device driver 1034, and a display driver 1036. Modem processor 1022 may perform processing for data transmission and reception, e.g., encoding, modulation, demodulation, decoding, etc. RISC/DSP 1024 may perform general and specialized processing for wireless device 1000. Controller/processor 1026 may direct the operation of various units within section 1020. Memory 1028 may store data and/or instructions for various units within section 1020.

[0059] Audio processor 1030 may perform encoding for input signals from a microphone 1040 and/or other audio sources. Audio processor 1030 may also perform decoding for coded audio data and may provide audio signals to audio drivers 1032. Audio drivers 1032 may drive a line-out device 1042, a headphone 1044, an earpiece 1046, and/or other audio devices. Audio drivers 1032 may include audio circuit 100 in FIG. 1. External device driver 1034 may drive an external device 1048 and/or may receive signals from the external device. Display driver 1036 may drive a display unit 1050.

[0060] As shown in FIG. 10, the multi-mode amplifier may be used in various blocks in which either DC or AC coupling is desirable. For example, the multi-mode amplifier may be used in audio drivers 1032, external device driver 1034, display driver 1036, etc. As a specific example, multi-mode amplifier 200a, 200b, 200c or 200d in FIG. 3, 4, 5A or 5B, respectively, may be used as a headphone amplifier in audio drivers 1032 to drive headphone 1044.

[0061] The multi-mode amplifier described herein may be implemented on an IC, an analog IC, a radio frequency IC (RFIC), a mixed-signal IC, an application specific integrated circuit (ASIC), a printed circuit board (PCB), an electronics device, etc. The multi-mode amplifier may also be fabricated with various IC process technologies such as complementary metal oxide semiconductor (CMOS), N-channel MOS (NMOS), P-channel MOS (PMOS), bipolar junction transistor (BJT), bipolar-CMOS (BiCMOS), silicon germanium (SiGe), gallium arsenide (GaAs), etc.

[0062] An apparatus implementing the multi-mode amplifier described herein may be a stand-alone device or may be part of a larger device. A device may be (i) a stand-alone IC, (ii) a set of one or more ICs that may include memory ICs for storing data and/or instructions, (iii) an RFIC such as an RF receiver (RFR) or an RF transmitter/receiver (RTR), (iv) an ASIC such as a mobile station modem (MSM), (v) a module that may be embedded within other devices, (vi) a receiver, cellular phone, wireless device, handset, or mobile unit, (vii) etc.

[0063] The previous description of the disclosure is provided to enable any person skilled in the art to make or use

the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

FURTHER SUMMARY OF THE INVENTION

[0064]

1. An apparatus comprising:

an amplifier configured to amplify an input signal and provide an output signal suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode; and
at least one DC level shifting circuit coupled to the amplifier and configured to perform DC level shifting for at least one common-mode voltage of the amplifier, the least one DC level shifting circuit being controlled based on whether the amplifier is operating in the DC-coupled mode or the AC-coupled mode.

2. The apparatus of 1, wherein the at least one DC level shifting circuit comprises
an output DC level shifting circuit configured to provide a first output common-mode voltage for the amplifier in the DC-coupled mode and to provide a second output common-mode voltage for the amplifier in the AC-coupled mode.

3. The apparatus of 2, wherein the output DC level shifting circuit comprises
a first current source configured to provide an offset current in the DC-coupled mode, the offset current being passed through a feedback resistor to an output of the amplifier, and
a second current source configured to draw the offset current at the output of the amplifier to a lower power supply.

4. The apparatus of 1, wherein the at least one DC level shifting circuit comprises
an input DC level shifting circuit configured to provide a first input common-mode voltage for the amplifier in the DC-coupled mode and to provide a second input common-mode voltage for the amplifier in the AC-coupled mode.

5. The apparatus of 1, wherein the amplifier comprises
an internal DC level shifting circuit configured to provide a first internal common-mode voltage for the amplifier in the DC-coupled mode and to provide a second internal common-mode voltage for the amplifier in the AC-coupled mode.

6. The apparatus of 1, wherein the amplifier has different input and output common-mode voltages in the DC-coupled mode and equal input and output common-mode voltages in the AC-coupled mode.

7. The apparatus of 1, wherein the amplifier has equal internal and output common-mode voltages in both the DC-coupled and AC-coupled modes.

8. The apparatus of 1, wherein the amplifier operates between an upper power supply and a first lower power supply in the DC-coupled mode and between the upper power supply and a second lower power supply in the AC-coupled mode.

9. The apparatus of 8, wherein the first lower power supply is a negative voltage and the second lower power supply is circuit ground.

10. The apparatus of 1, wherein the amplifier comprises at least one gain stage configured to provide amplification for the input signal, an internal DC level shifting circuit configured to provide a first internal common-mode voltage in the DC-coupled mode and to provide a second internal common-mode voltage in the AC-coupled mode, and an output stage configured to provide signal drive for the output signal.

11. The apparatus of 1, wherein the amplifier comprises
an input gain stage configured to receive and amplify the input signal, the input gain stage having same input common-mode voltage for both the DC-coupled and AC-coupled modes.

12. The apparatus of 11, wherein the input gain stage operates between an upper power supply and circuit ground

for both the DC-coupled and AC-coupled modes.

13. The apparatus of 1, wherein the amplifier comprises
 a first output drive section configured to provide signal drive for the output signal in both the DC-coupled and AC-coupled modes, and
 a second output drive section coupled in parallel with the first output drive section and being disabled in the DC-coupled mode and enabled in the AC-coupled mode to provide additional signal drive for the output signal.

14. The apparatus of 1, wherein the amplifier comprises
 at least one stage implemented with thin-oxide transistors having a first operating voltage, and
 at least one additional stage implemented with thick-oxide transistors having a second operating voltage higher than the first operating voltage.

15. The apparatus of 1, wherein the amplifier comprises
 at least one capacitor configured to provide compensation for the amplifier and controlled based on whether the amplifier is operating in the DC-coupled mode or the AC-coupled mode.

16. The apparatus of 1, wherein the amplifier is operated as a headphone amplifier and configured to provide the output signal for a headphone.

17. An integrated circuit comprising:

an amplifier configured to amplify an input signal and provide an output signal suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode; and
 at least one DC level shifting circuit coupled to the amplifier and configured to perform DC level shifting for at least one common-mode voltage of the amplifier, the least one DC level shifting circuit being controlled based on whether the amplifier is operating in the DC-coupled mode or the AC-coupled mode.

18. The integrated circuit of 17, wherein the at least one DC level shifting circuit comprises
 an output DC level shifting circuit configured to provide a first output common-mode voltage for the amplifier in the DC-coupled mode and to provide a second output common-mode voltage for the amplifier in the AC-coupled mode.

19. The integrated circuit of 17, wherein the amplifier comprises
 an internal DC level shifting circuit configured to provide a first internal common-mode voltage for the amplifier in the DC-coupled mode and to provide a second internal common-mode voltage for the amplifier in the AC-coupled mode.

20. The integrated circuit of 17, wherein the amplifier comprises at least one gain stage configured to provide amplification for the input signal, an internal DC level shifting circuit configured to provide a first internal common-mode voltage in the DC-coupled mode and to provide a second internal common-mode voltage in the AC-coupled mode, and
 an output stage configured to provide signal drive for the output signal.

21. The integrated circuit of 17, wherein the amplifier comprises
 a first output drive section configured to provide signal drive for the output signal in both the DC-coupled and AC-coupled modes, and
 a second output drive section coupled in parallel with the first output drive section and being disabled in the DC-coupled mode and enabled in the AC-coupled mode to provide additional signal drive for the output signal.

22. A wireless communication device comprising:

a headphone amplifier comprising
 an amplifier configured to amplify an input signal and provide an output signal suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode, and
 at least one DC level shifting circuit coupled to the amplifier and configured to perform DC level shifting for at least one common-mode voltage of the amplifier, the least one DC level shifting circuit being controlled based on whether the amplifier is operating in the DC-coupled mode or the AC-coupled mode.

23. A method comprising:

amplifying an input signal to obtain an output signal suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode; and
performing DC level shifting as needed to obtain a first output common-mode voltage for the output signal in the DC-coupled mode and to obtain a second output common-mode voltage for the output signal in the AC-coupled mode.

24. The method of 23, further comprising:

performing DC level shifting as needed to obtain a first internal common-mode voltage in the DC-coupled mode and to obtain a second internal common-mode voltage in the AC-coupled mode.

25. The method of 23, wherein the performing DC level shifting comprises

generating an offset current to obtain a DC voltage difference between the input signal and the output signal, and drawing the offset current to a lower power supply to prevent the offset current from passing to the output signal.

26. The method of 23, wherein the amplifying the input signal comprises

amplifying the input signal using an upper power supply and a first lower power supply in the DC-coupled mode, and amplifying the input signal using the upper power supply and a second lower power supply in the AC-coupled mode.

27. The method of 23, wherein the amplifying the input signal comprises

driving the output signal with a first output drive section in both the DC-coupled and AC-coupled modes, and driving the output signal further with a second output drive section in the AC-coupled mode.

28. An apparatus comprising:

means for amplifying an input signal to obtain an output signal suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode; and
means for performing DC level shifting as needed to obtain a first output common-mode voltage for the output signal in the DC-coupled mode and to obtain a second output common-mode voltage for the output signal in the AC-coupled mode.

29. The apparatus of 28, further comprising:

means for performing DC level shifting as needed to obtain a first internal common-mode voltage in the DC-coupled mode and to obtain a second internal common-mode voltage in the AC-coupled mode.

30. The apparatus of 28, wherein the means for performing DC level shifting comprises

means for generating an offset current to obtain a DC voltage difference between the input signal and the output signal, and
means for drawing the offset current to a lower power supply to prevent the offset current from passing to the output signal.

31. The apparatus of 28, wherein the means for amplifying the input signal comprises

means for amplifying the input signal using an upper power supply and a first lower power supply in the DC-coupled mode, and
means for amplifying the input signal using the upper power supply and a second lower power supply in the AC-coupled mode.

32. The apparatus of 28, wherein the means for amplifying the input signal comprises

means for driving the output signal in both the DC-coupled and AC-coupled modes, and
means for further driving the output signal in the AC-coupled mode.

Claims

1. A method comprising:

amplifying an input signal to obtain an output signal suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode; and
 performing DC level shifting as needed to obtain a first output common-mode voltage for the output signal in the DC-coupled mode and to obtain a second output common-mode voltage for the output signal in the AC-coupled mode, wherein the performing DC level shifting comprises
 generating an offset current to obtain a DC voltage difference between the input signal and the output signal, and
 drawing the offset current to a lower power supply to prevent the offset current from passing to the output signal.

2. The method of claim 1, further comprising:

performing DC level shifting as needed to obtain a first internal common-mode voltage in the DC-coupled mode and to obtain a second internal common-mode voltage in the AC-coupled mode.

3. The method of claim 1, wherein the amplifying the input signal comprises

amplifying the input signal using an upper power supply and a first lower power supply in the DC-coupled mode, and
 amplifying the input signal using the upper power supply and a second lower power supply in the AC-coupled mode.

4. The method of claim 1, wherein the amplifying the input signal comprises

driving the output signal with a first output drive section in both the DC-coupled and AC-coupled modes, and
 driving the output signal further with a second output drive section in the AC-coupled mode.

5. An apparatus comprising:

means for amplifying an input signal to obtain an output signal suitable for DC coupling to a load in a DC-coupled mode and for AC coupling to the load in an AC-coupled mode; and
 means for performing DC level shifting as needed to obtain a first output common-mode voltage for the output signal in the DC-coupled mode and to obtain a second output common-mode voltage for the output signal in the AC-coupled mode, wherein the means for performing DC level shifting comprises
 means for generating an offset current to obtain a DC voltage difference between the input signal and the output signal, and
 means for drawing the offset current to a lower power supply to prevent the offset current from passing to the output signal.

6. The apparatus of claim 5, further comprising:

means for performing DC level shifting as needed to obtain a first internal common-mode voltage in the DC-coupled mode and to obtain a second internal common-mode voltage in the AC-coupled mode.

7. The apparatus of claim 5, wherein the means for amplifying the input signal comprises

means for amplifying the input signal using an upper power supply and a first lower power supply in the DC-coupled mode, and
 means for amplifying the input signal using the upper power supply and a second lower power supply in the AC-coupled mode.

8. The apparatus of claim 5, wherein the means for amplifying the input signal comprises

means for driving the output signal in both the DC-coupled and AC-coupled modes, and
 means for further driving the output signal in the AC-coupled mode.

9. The apparatus of claim 6, wherein the means are implemented as:

an amplifier configured to amplify said input signal and provide said output signal suitable for DC coupling to a load in said DC-coupled mode and for AC coupling to the load in said AC-coupled mode; and
 at least one DC level shifting circuit coupled to the amplifier and configured to perform DC level shifting for at least one common-mode voltage of the amplifier, the least one DC level shifting circuit being controlled based on whether the amplifier is operating in the DC-coupled mode or the AC-coupled mode.

10. The apparatus of claim 9, wherein the at least one DC level shifting circuit comprises

an output DC level shifting circuit configured to provide a first output common-mode voltage for the amplifier in the

DC-coupled mode and to provide a second output common-mode voltage for the amplifier in the AC-coupled mode.

- 5 **11.** The apparatus of claim 10, wherein the output DC level shifting circuit comprises
a first current source configured to provide an offset current in the DC-coupled mode, the offset current being passed
through a feedback resistor to an output of the amplifier, and
a second current source configured to draw the offset current at the output of the amplifier to a lower power supply.
- 10 **12.** The apparatus of claim 9, wherein the at least one DC level shifting circuit comprises
an input DC level shifting circuit configured to provide a first input common-mode voltage for the amplifier in the DC-
coupled mode and to provide a second input common-mode voltage for the amplifier in the AC-coupled mode.
- 15 **13.** The apparatus of claim 9, wherein the amplifier comprises
an internal DC level shifting circuit configured to provide a first internal common-mode voltage for the amplifier in
the DC-coupled mode and to provide a second internal common-mode voltage for the amplifier in the AC-coupled
mode.

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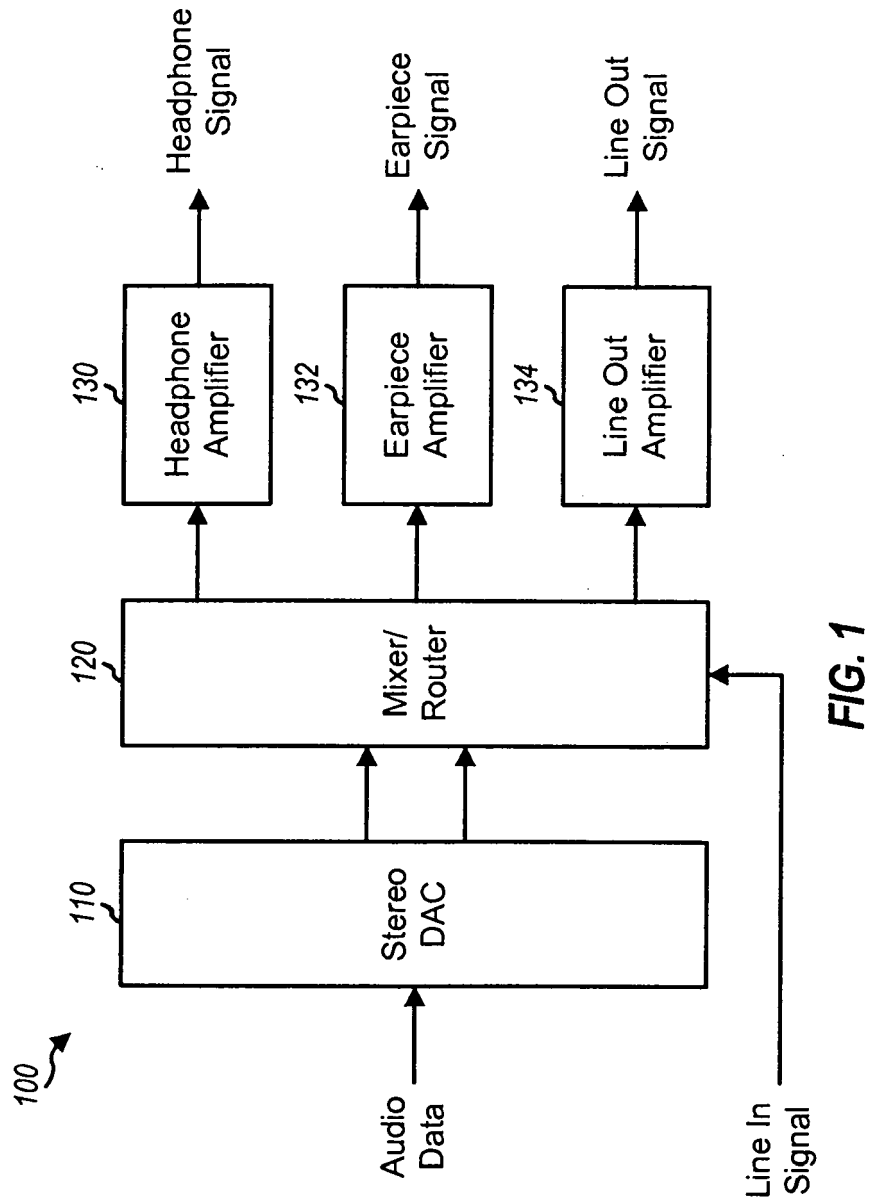


FIG. 1

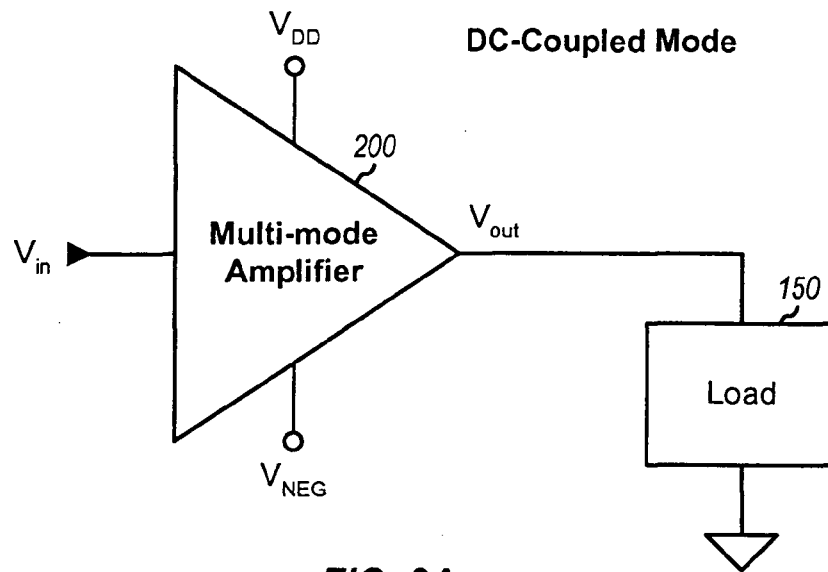


FIG. 2A

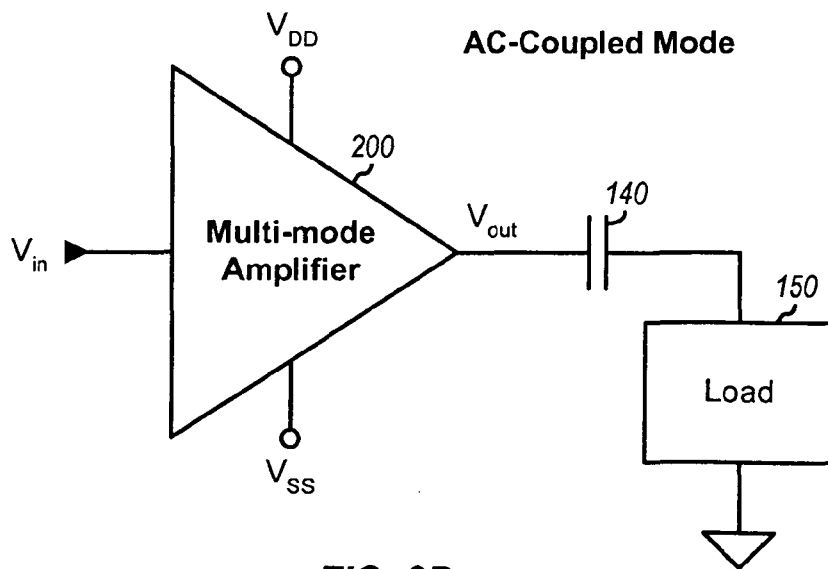


FIG. 2B

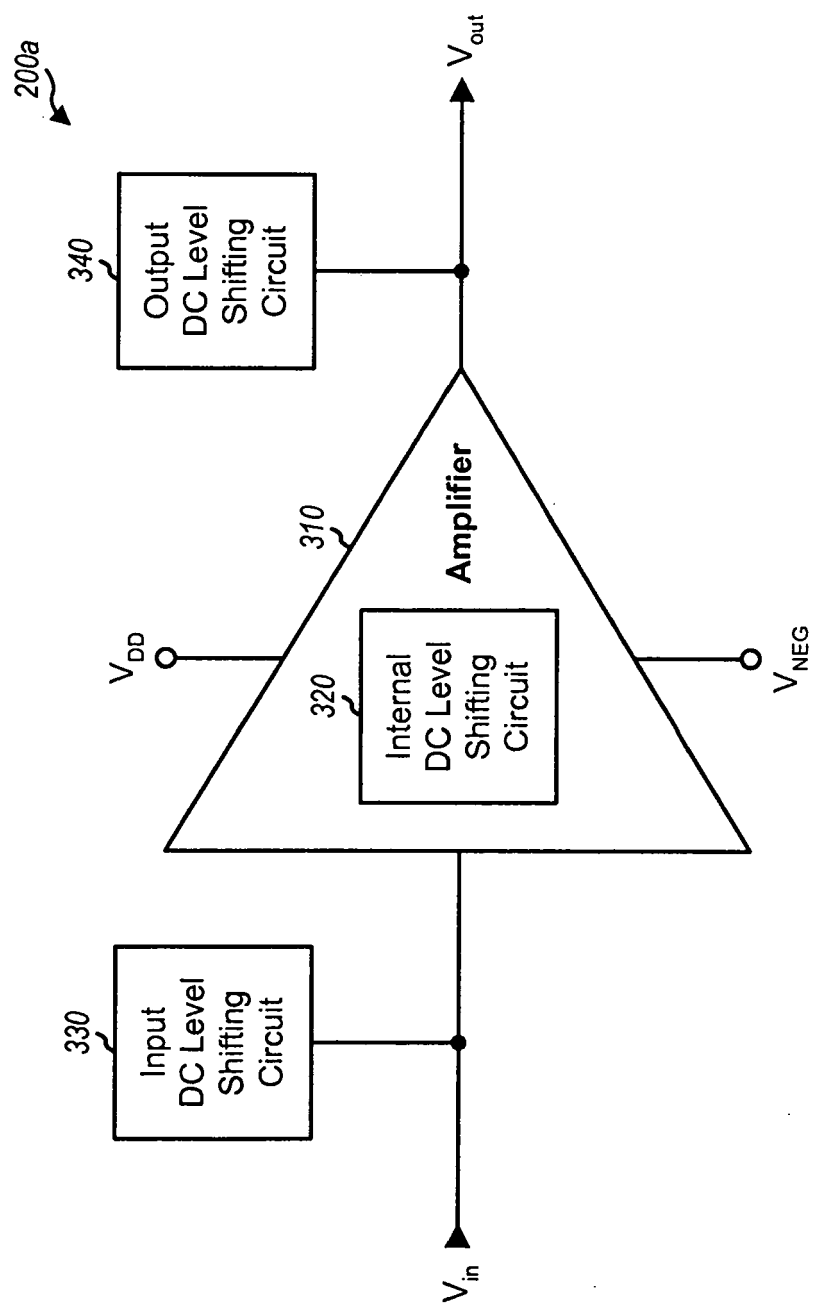


FIG. 3

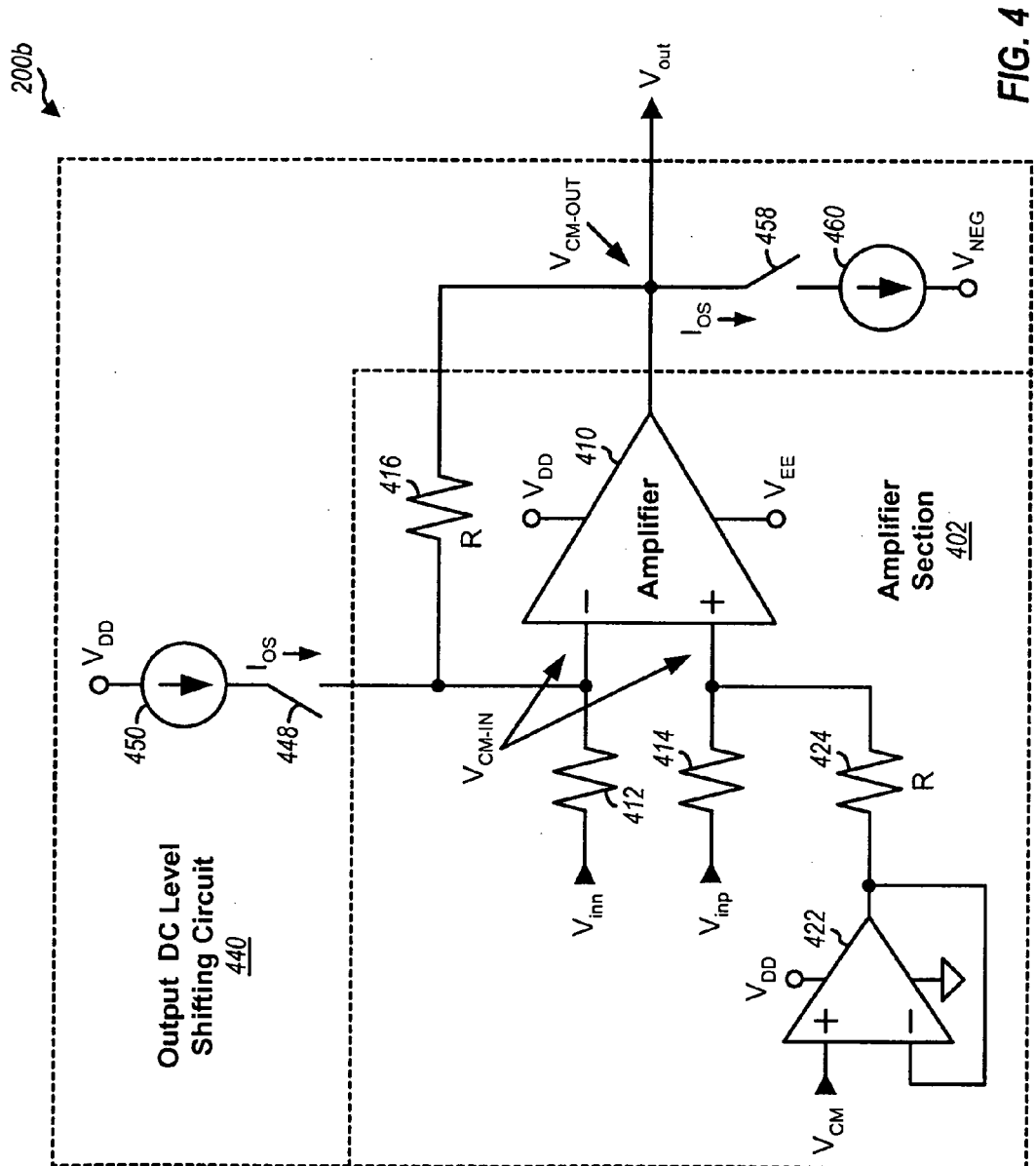
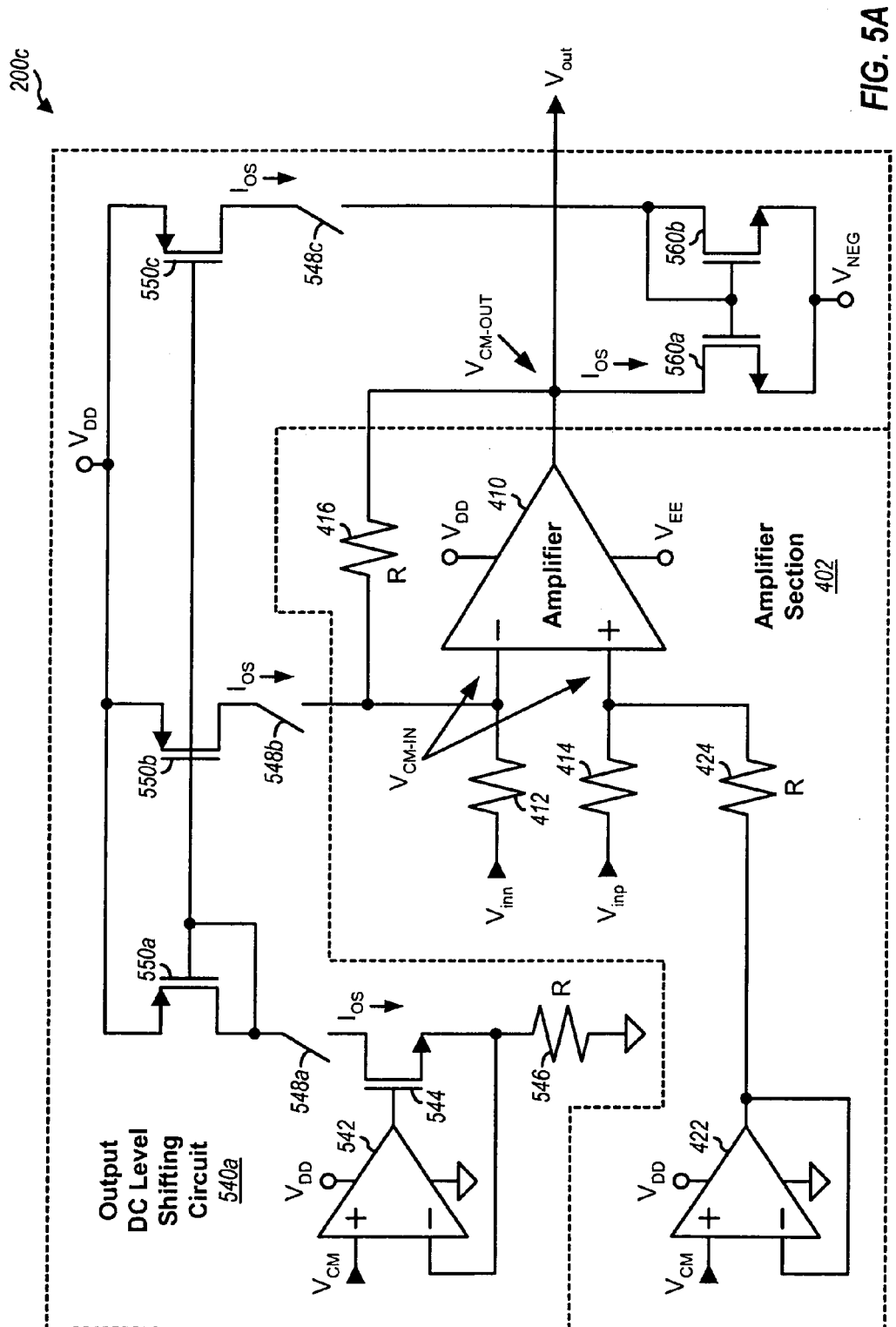


FIG. 4



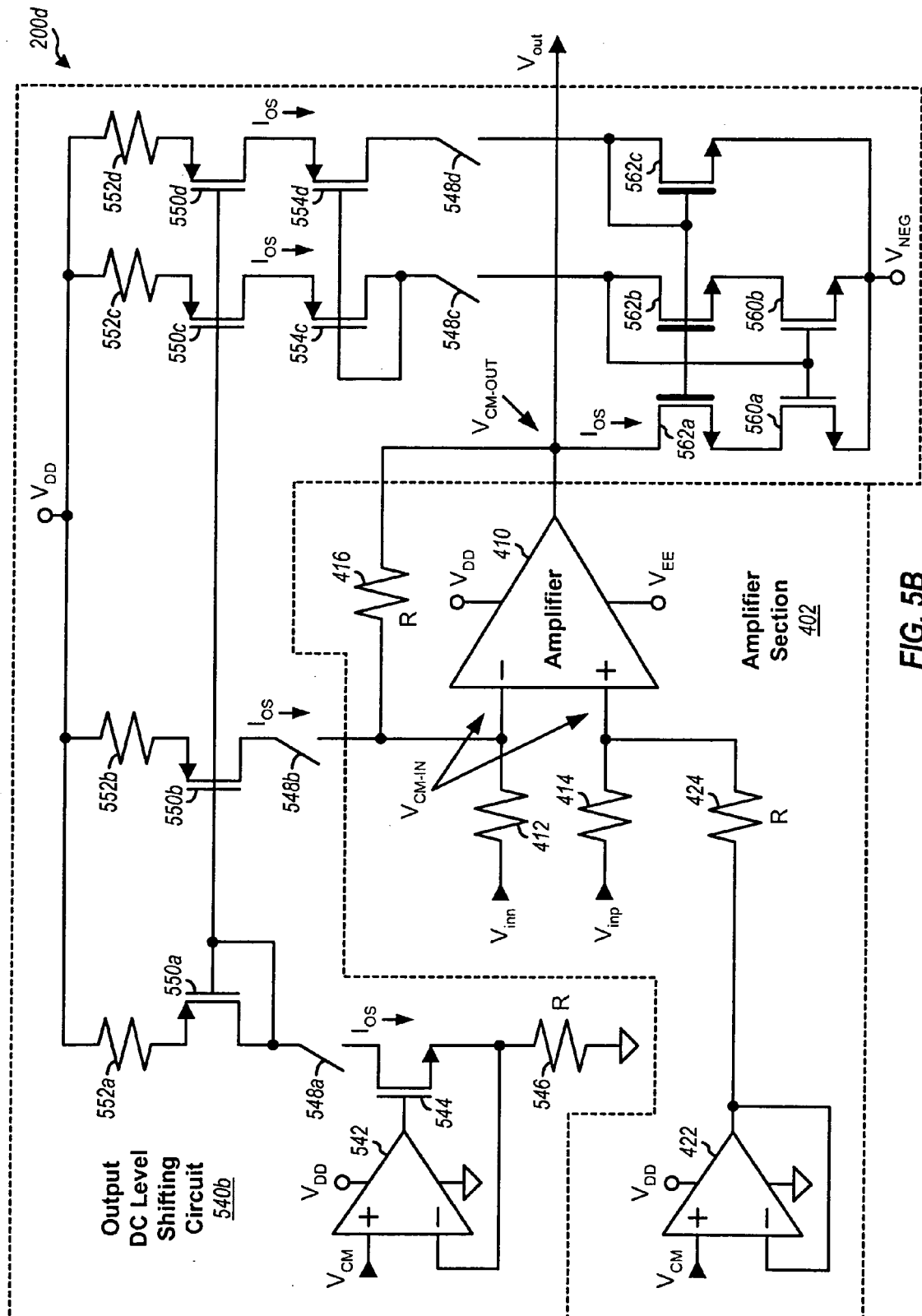


FIG. 5B

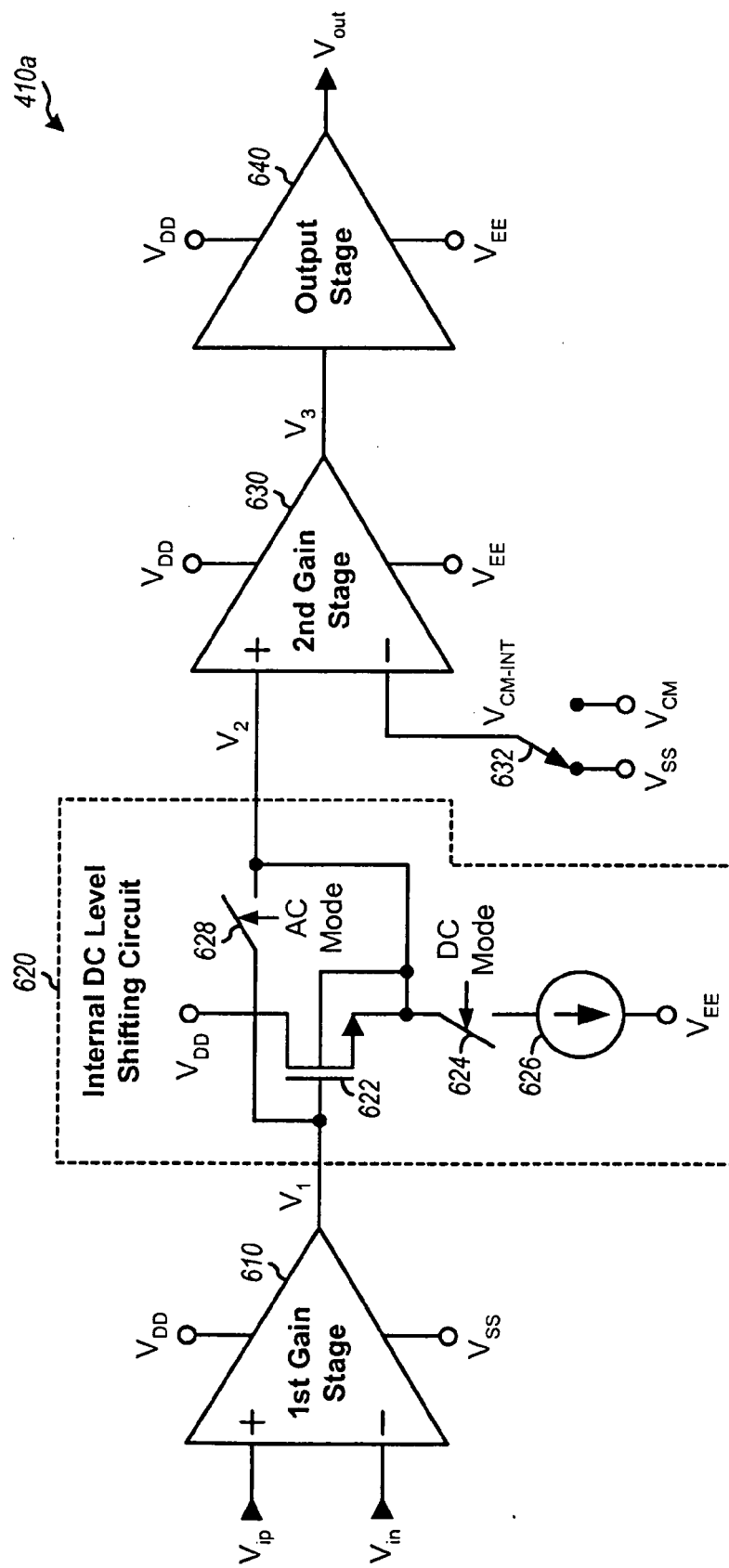


FIG. 6

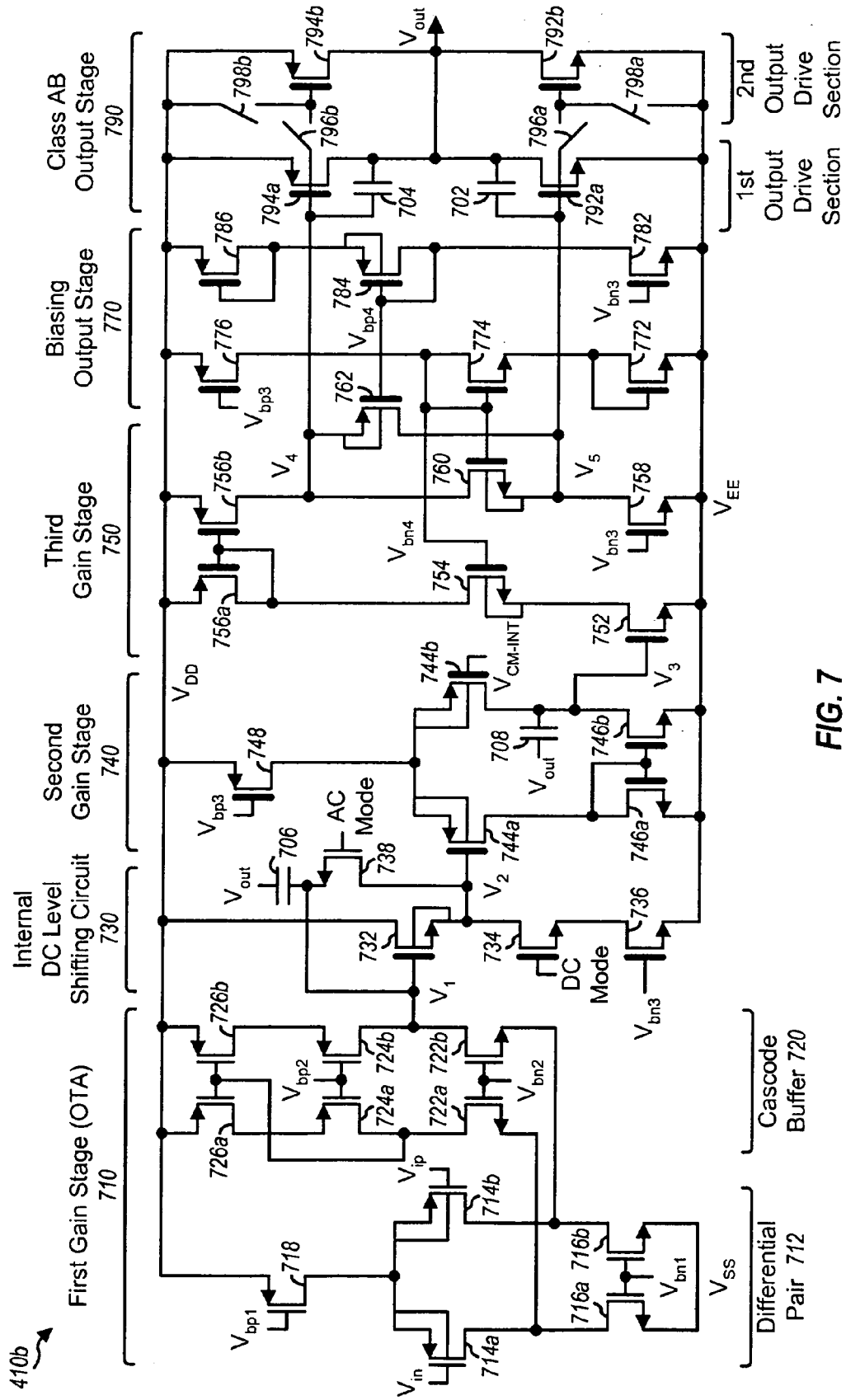


FIG. 7

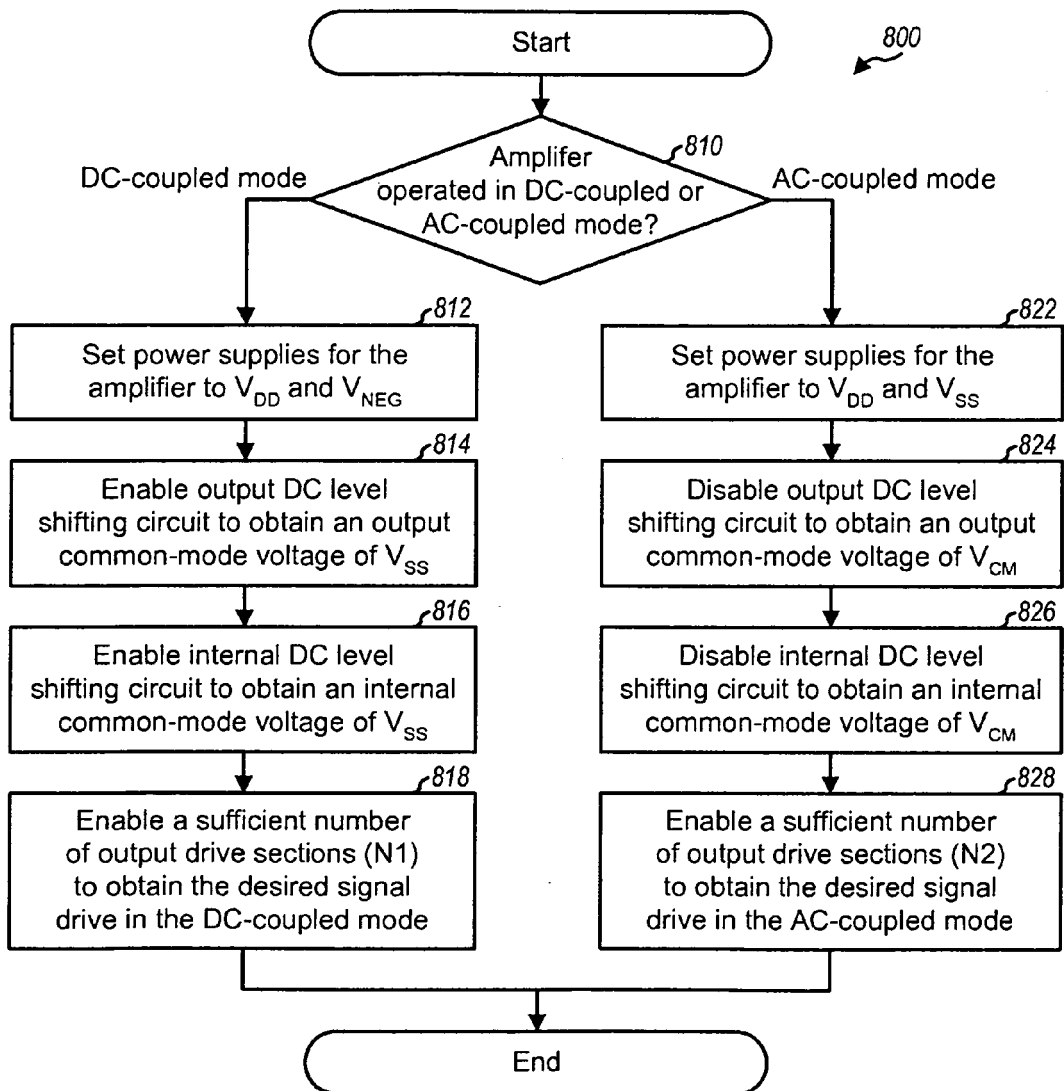
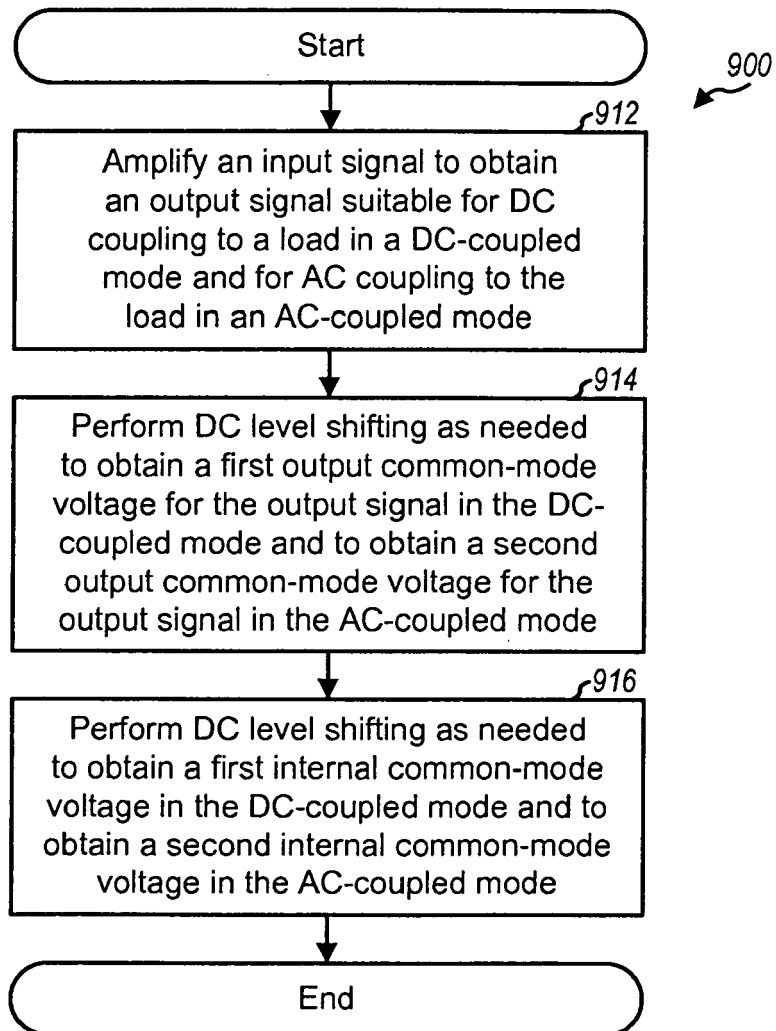


FIG. 8

**FIG. 9**

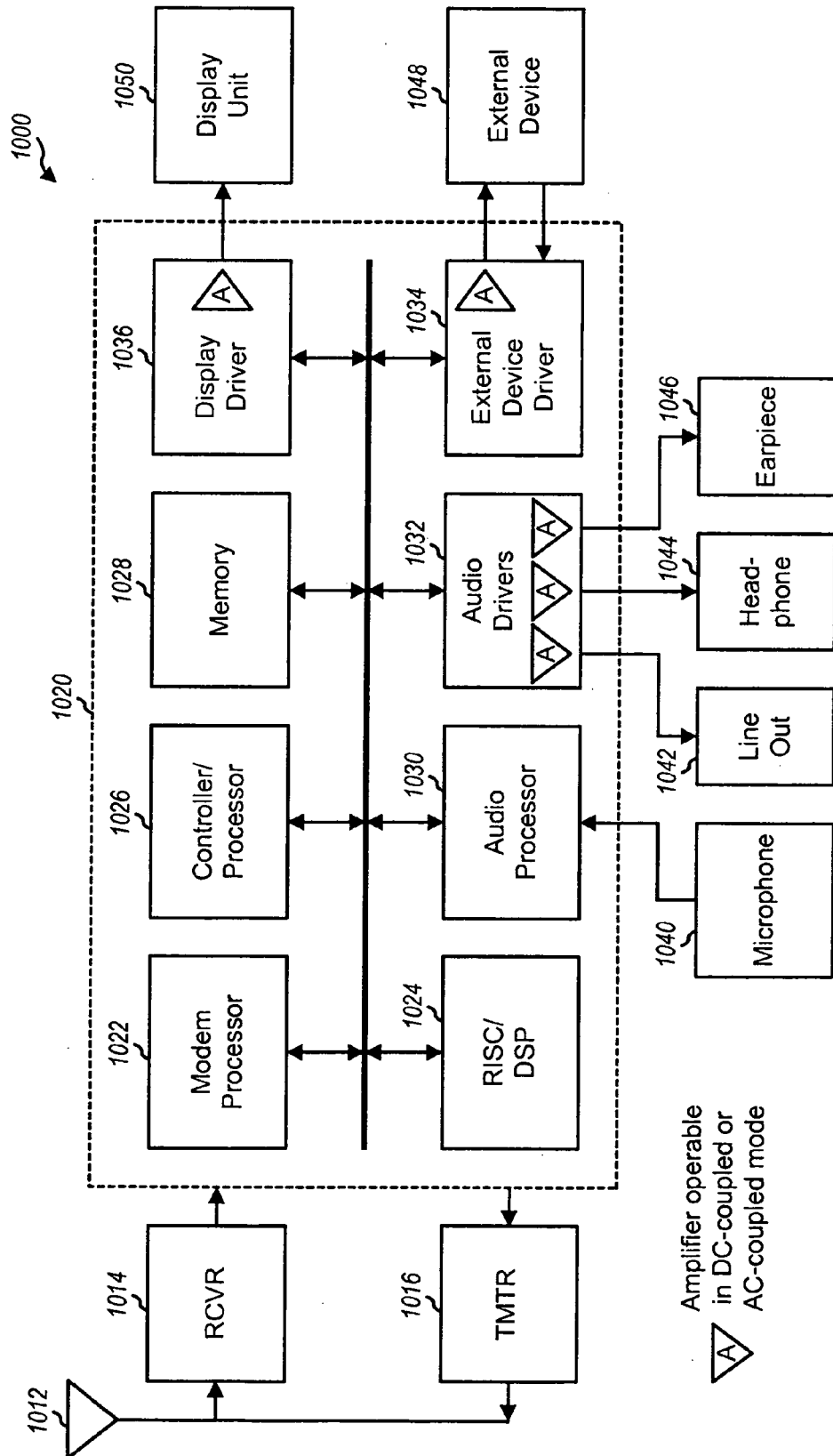


FIG. 10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 60947313 B [0001]